ATMOSPHERIC AEROSOLS: THEIR INFLUENCES ON CLIMATE AND WHY IT IS ESSENTIAL THAT WE UNDERSTAND THEM

Stephen E. Schwartz

BROOKHAVEN NATIONAL LABORATORY

Chemical Sciences Roundtable

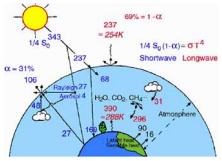
Washington DC

February 2, 2010

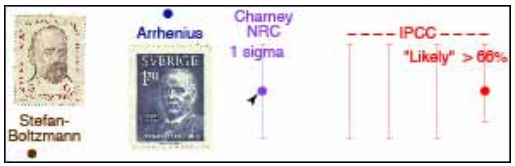
www.ecd.bnl.gov/steve

OVERVIEW

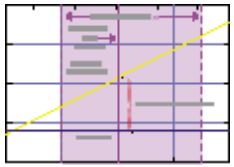
"*You have a short course... not a 20 min talk.*" – BJF-P



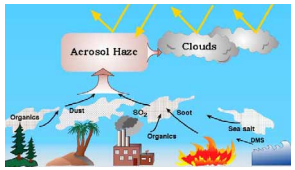
Earth's energy balance and perturbations



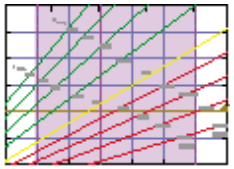
Climate sensitivity – definition, importance, past and current estimates



Expected increase in global mean surface temperature and the ***warming discrepancy***



Aerosol forcing and implications



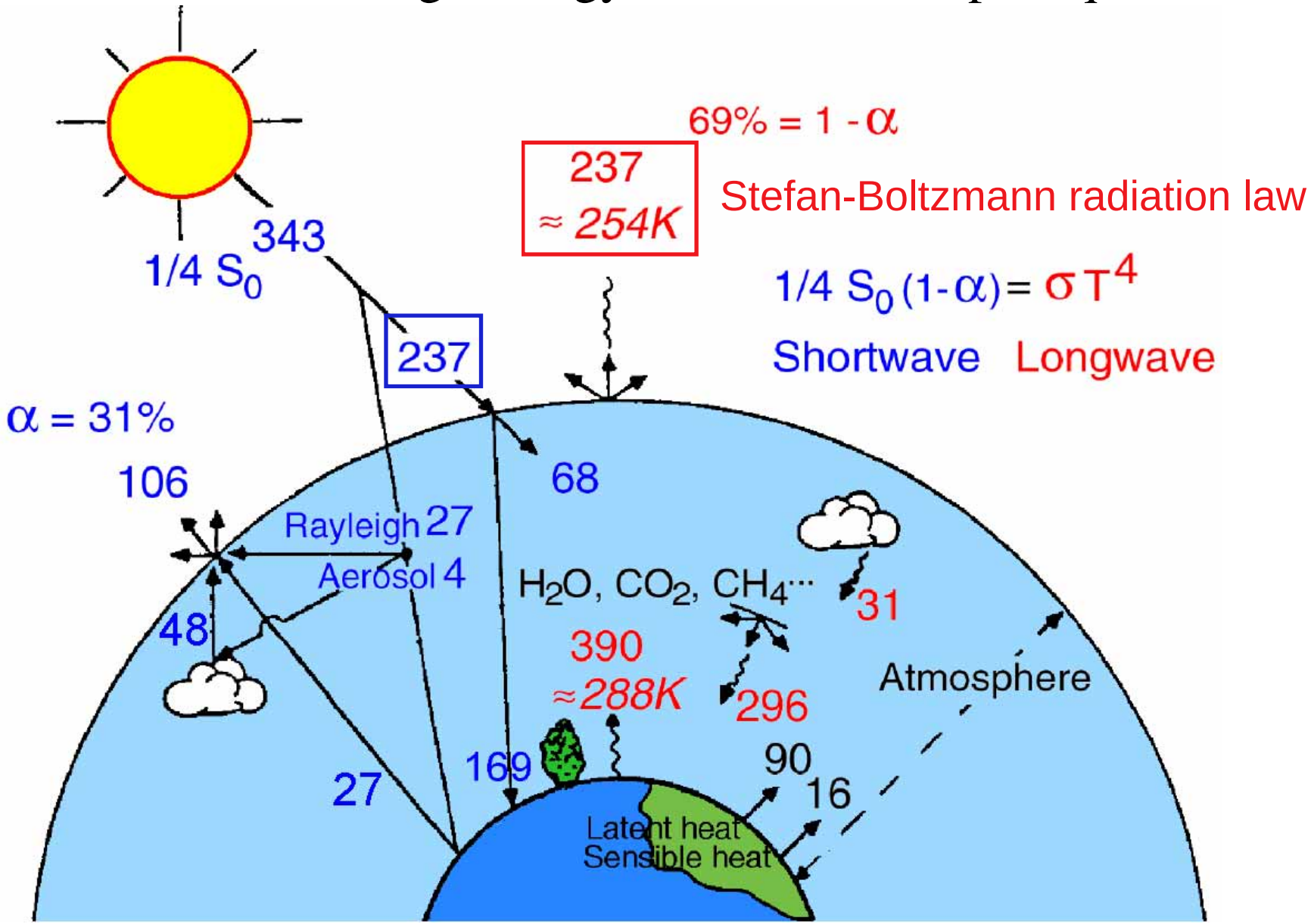
Allowable future CO_2 emissions

The path forward

Concluding remarks – Importance

GLOBAL ENERGY BALANCE

Global and annual average energy fluxes in watts per square meter



Schwartz, 1996, modified from Ramanathan, 1987

RADIATIVE FORCING

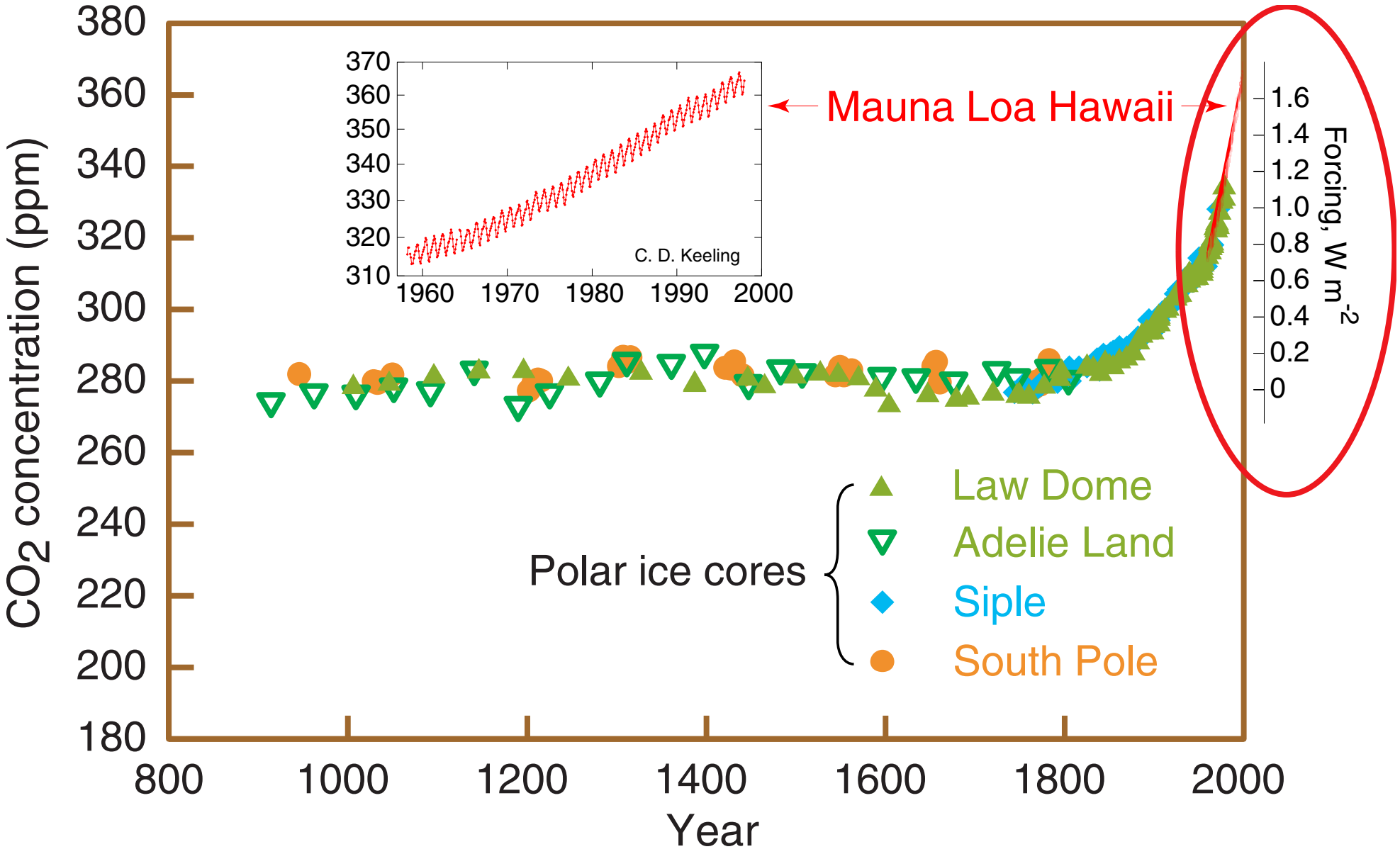
A ***change*** in a radiative flux term in Earth's radiation budget, ΔF, W m^{-2}.

Working hypothesis:

On a global basis radiative forcings are additive and fungible.

- This hypothesis is fundamental to the radiative forcing concept.
- This hypothesis underlies much of the assessment of climate change over the industrial period.

ATMOSPHERIC CARBON DIOXIDE IS INCREASING



Global carbon dioxide concentration and infrared radiative forcing over the last thousand years

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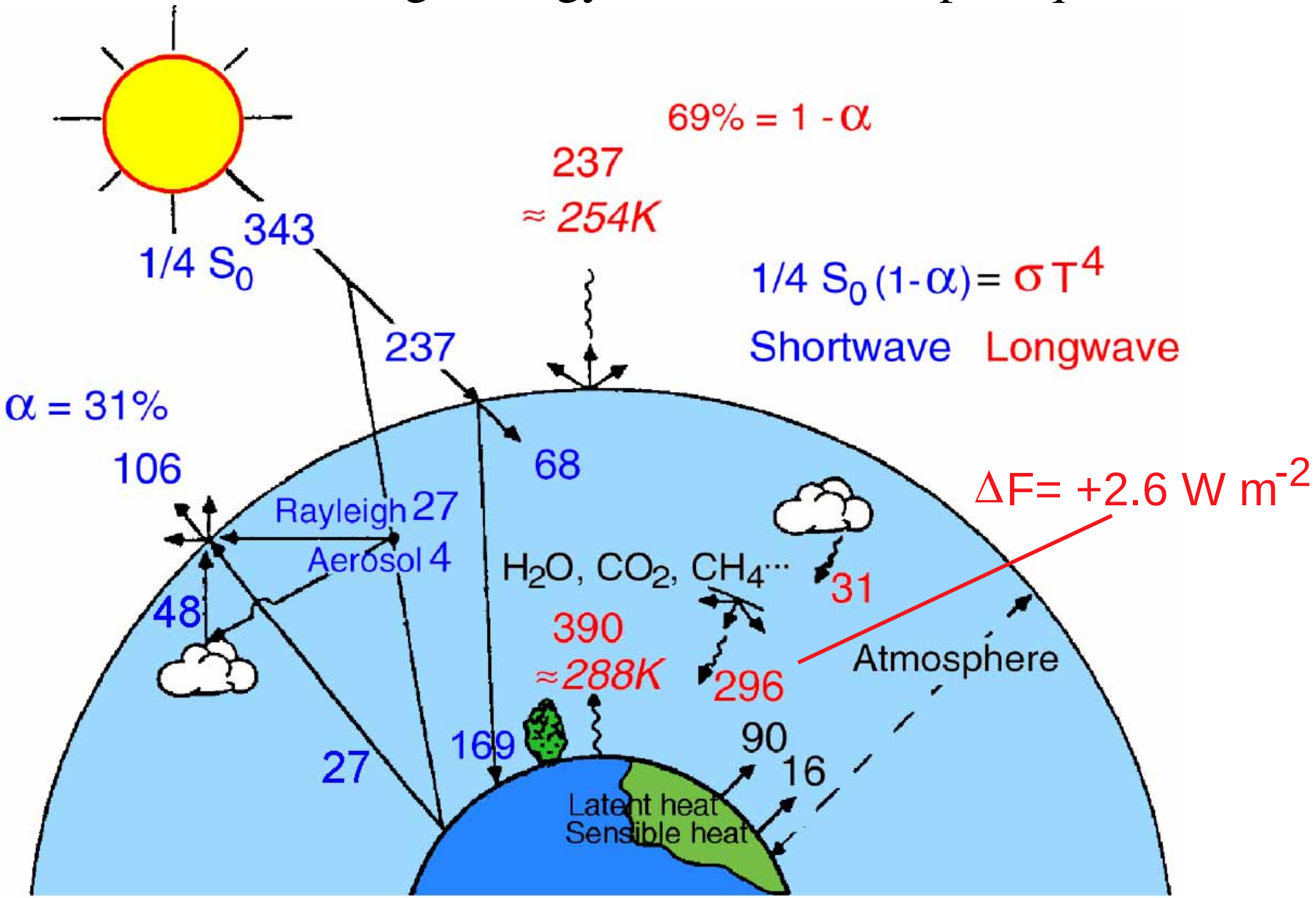
Global and annual average energy fluxes in watts per square meter



Schwartz, 1996, modified from Ramanathan, 1987

CLIMATE RESPONSE

The ***change*** in global and annual mean temperature, ΔT, K, resulting from a given radiative forcing.

Working hypothesis:

The change in global mean temperature is proportional to the forcing, but independent of its nature and spatial distribution.

$$\Delta T = S\,\Delta F$$

CLIMATE SENSITIVITY

The ***change*** in global and annual mean temperature per unit forcing, S, K/(W m^{-2}),

$$S = \Delta T/\Delta F.$$

Climate sensitivity is not known and is the objective of much current research on climate change.

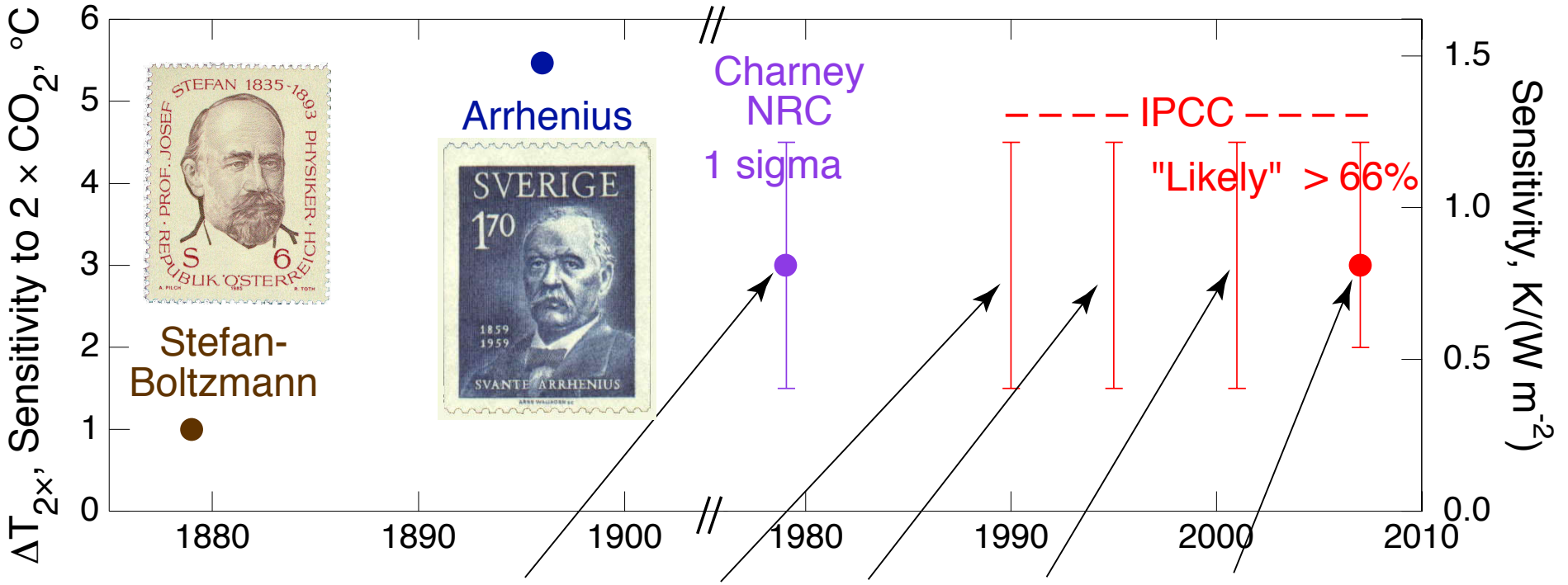
Climate sensitivity is often expressed as the temperature for doubled CO_2 concentration $\Delta T_{2\times}$.

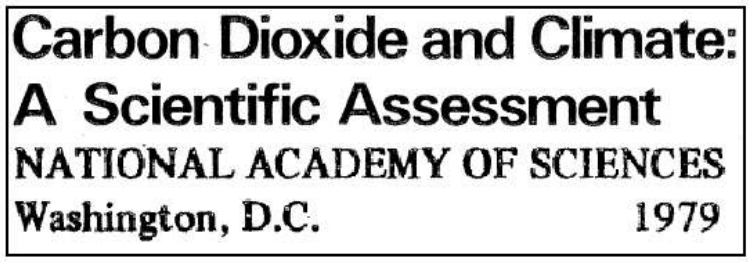
$$\Delta T_{2\times} = S\Delta F_{2\times}$$

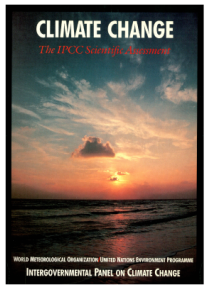
$$\Delta F_{2\times} \approx 3.7 \text{ W m}^{-2}$$

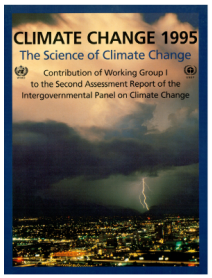
CLIMATE SENSITIVITY ESTIMATES THROUGH THE AGES

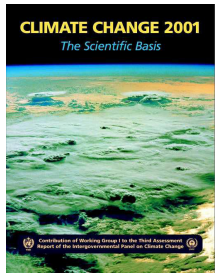
Estimates of central value and uncertainty range from major national and international assessments

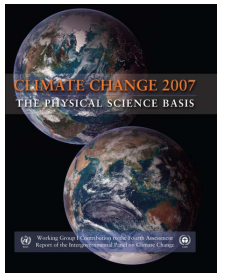








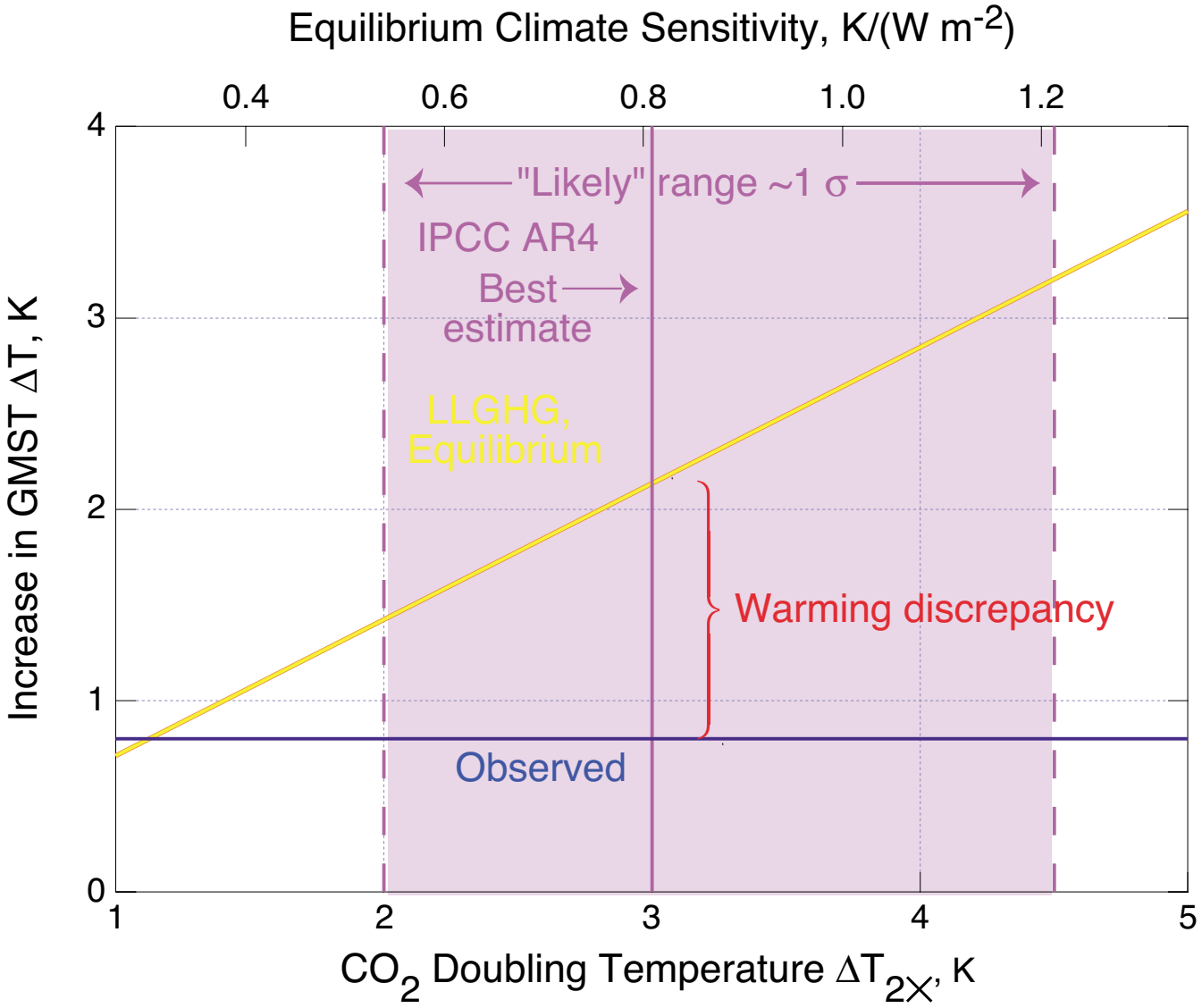




Despite extensive research, climate sensitivity remains ***highly uncertain***.

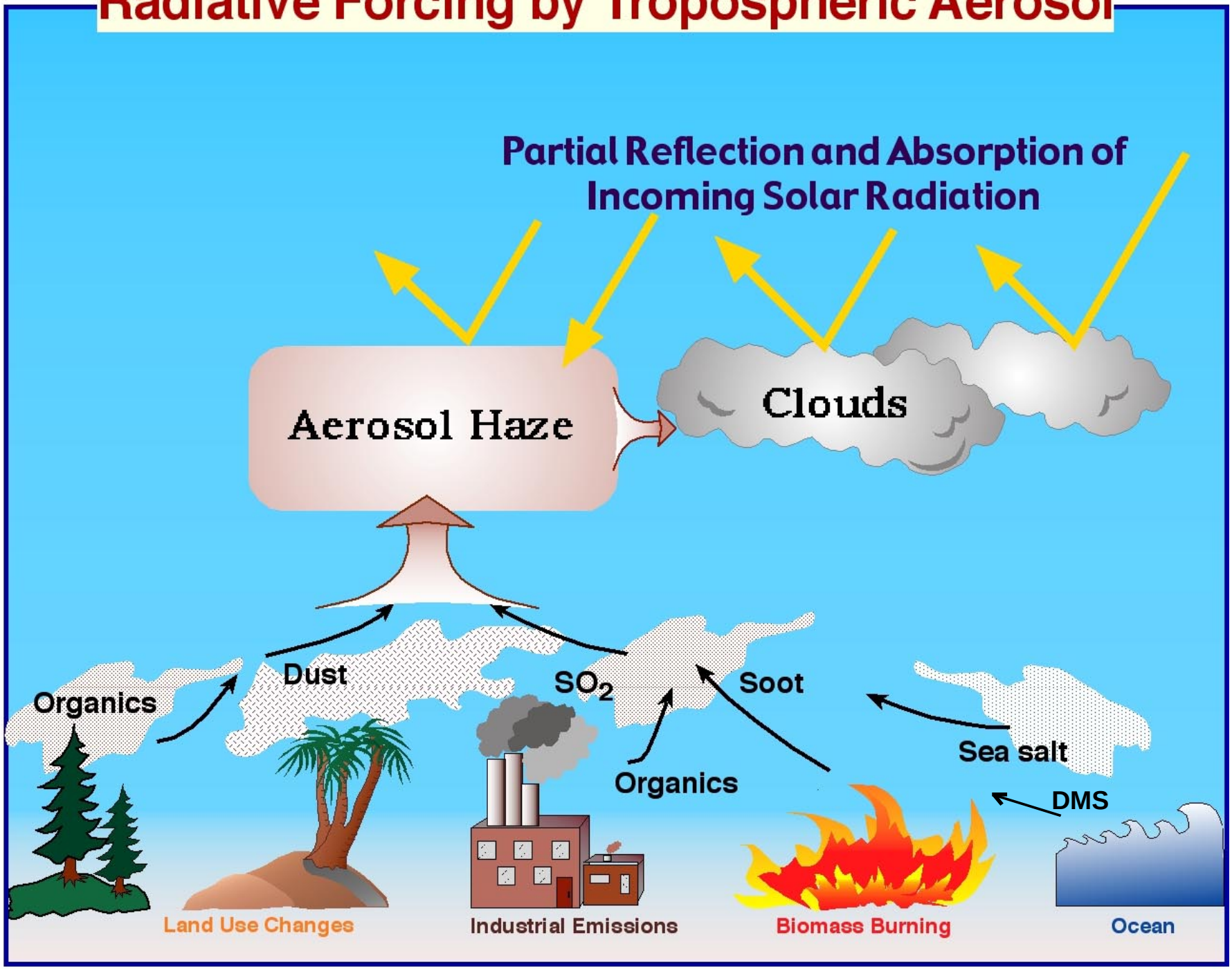
EXPECTED INCREASE IN GLOBAL TEMPERATURE

Long-lived GHGs only – Dependence on climate sensitivity

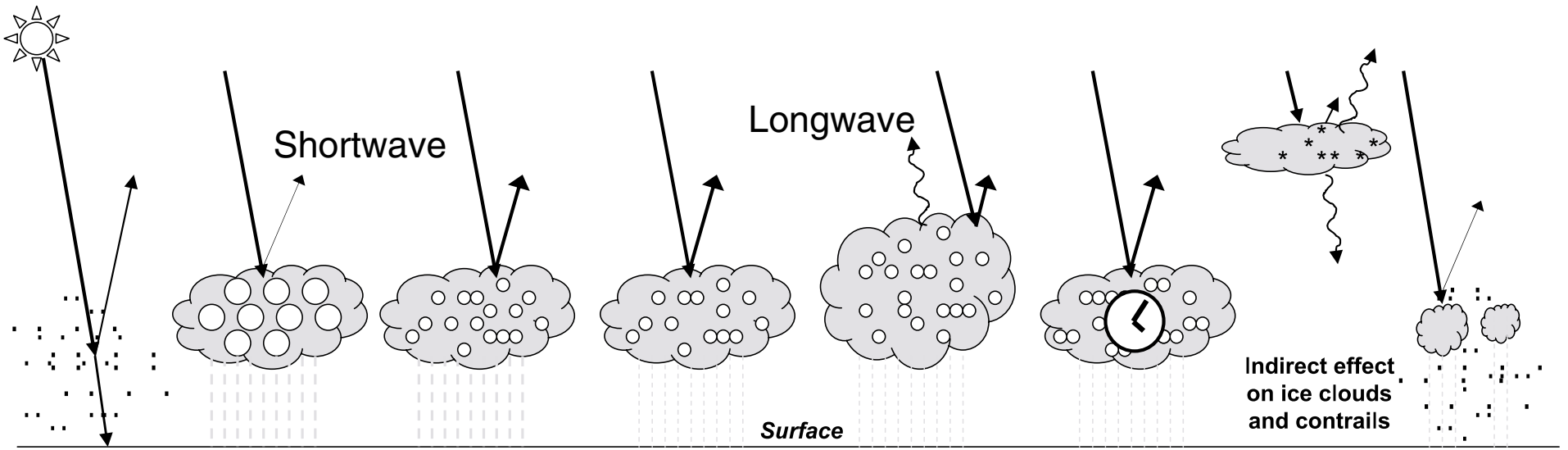


This discrepancy holds throughout the IPCC AR4 “likely” range for climate sensitivity.

Radiative Forcing by Tropospheric Aerosol



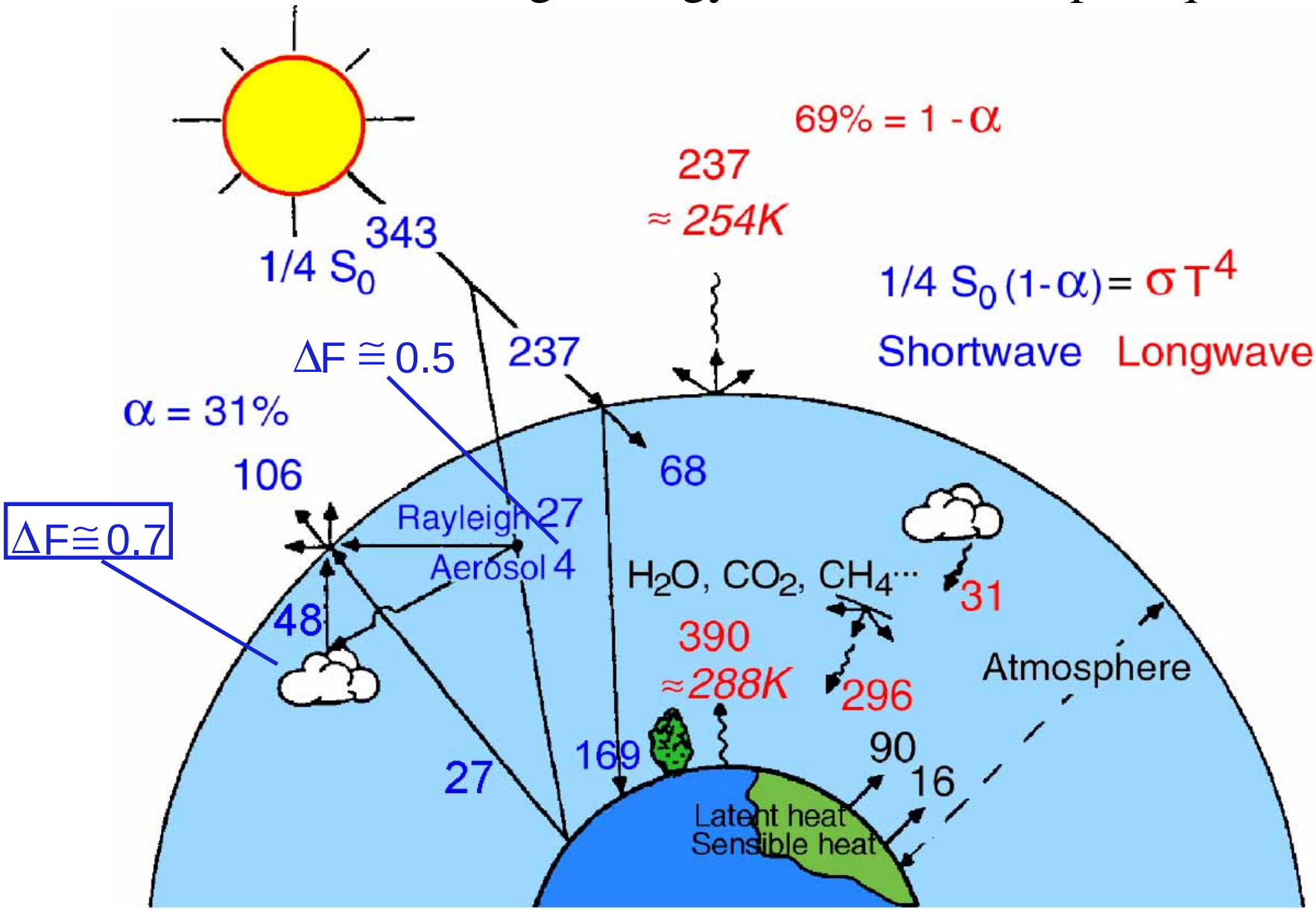
AEROSOL EFFECTS ON CLOUDS AND RADIATION



IPCC AR4 (2007) after Boucher and Haywood, 2000

GLOBAL ENERGY BALANCE

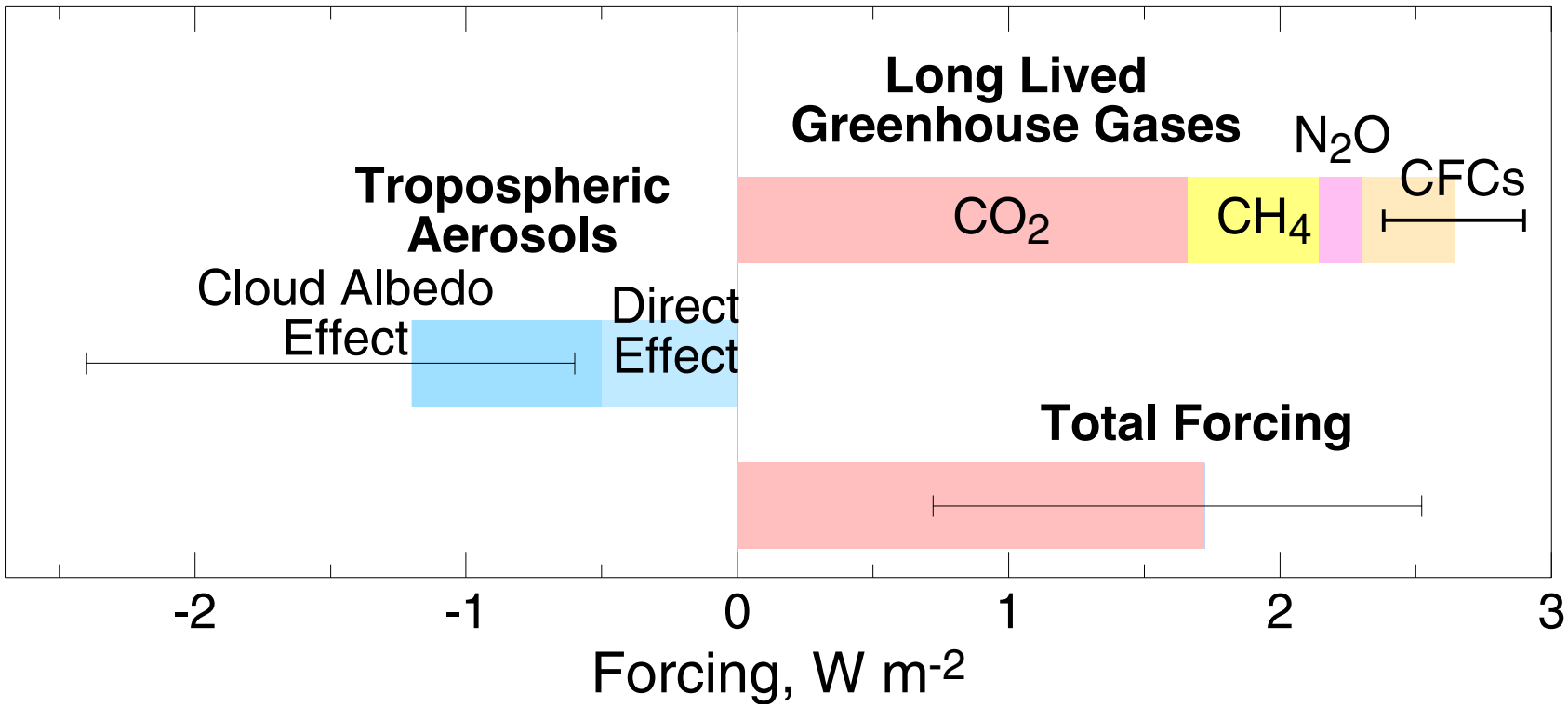
Global and annual average energy fluxes in watts per square meter



Schwartz, 1996, modified from Ramanathan, 1987

CLIMATE FORCINGS OVER THE INDUSTRIAL PERIOD

Extracted from IPCC AR4 (2007)



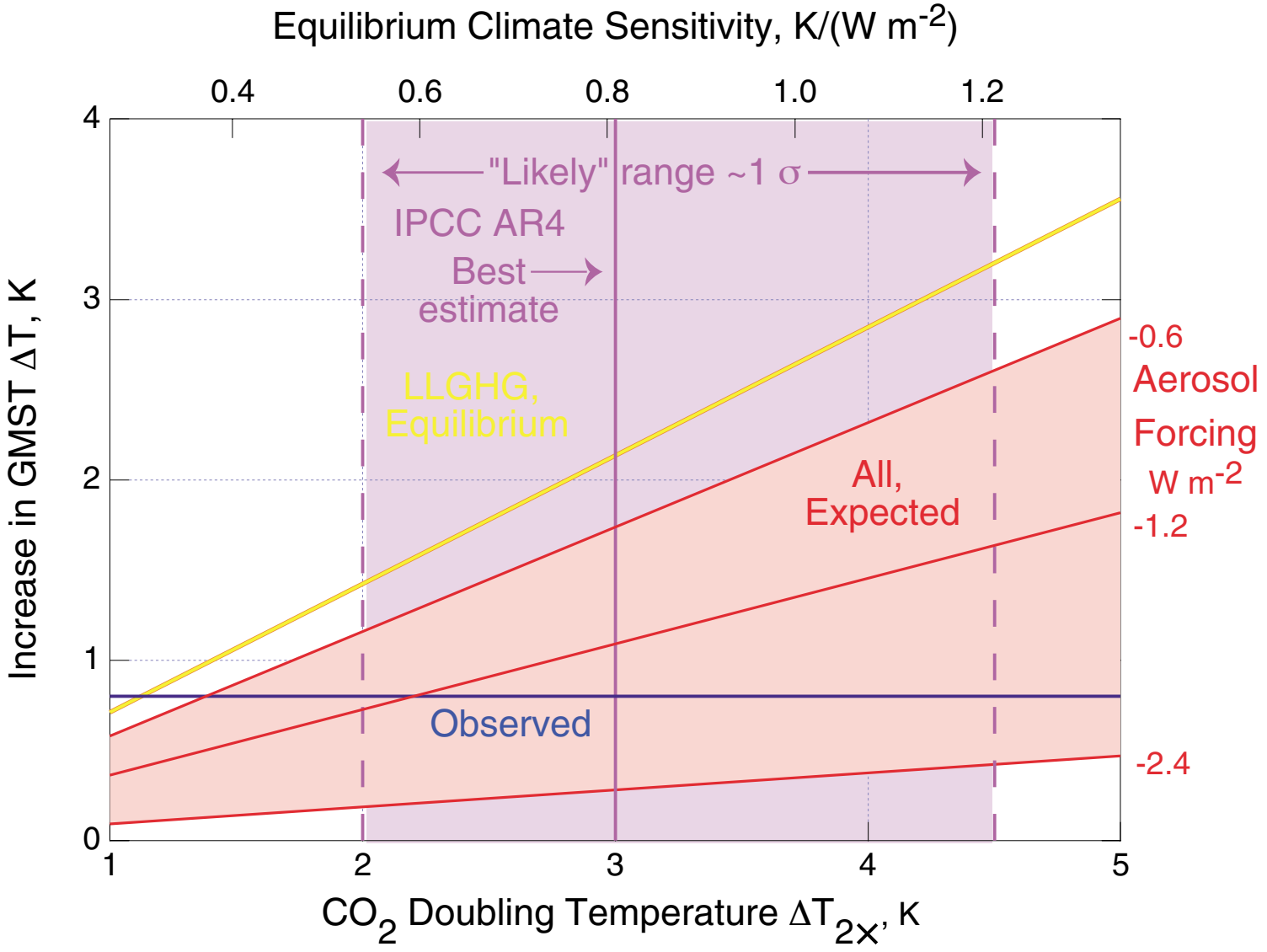
Total forcing includes other anthropogenic and natural (solar) forcings.

Forcing by tropospheric ozone, ~0.35 W m^{-2}, is the greatest of these.

Uncertainty in aerosol forcing dominates uncertainty in total forcing.

EXPECTED INCREASE IN GLOBAL TEMPERATURE

Long-lived GHGs only – Dependence on climate sensitivity



The warming discrepancy is certainly resolved by countervailing aerosol forcing (within the IPCC range) for virtually any value of sensitivity.

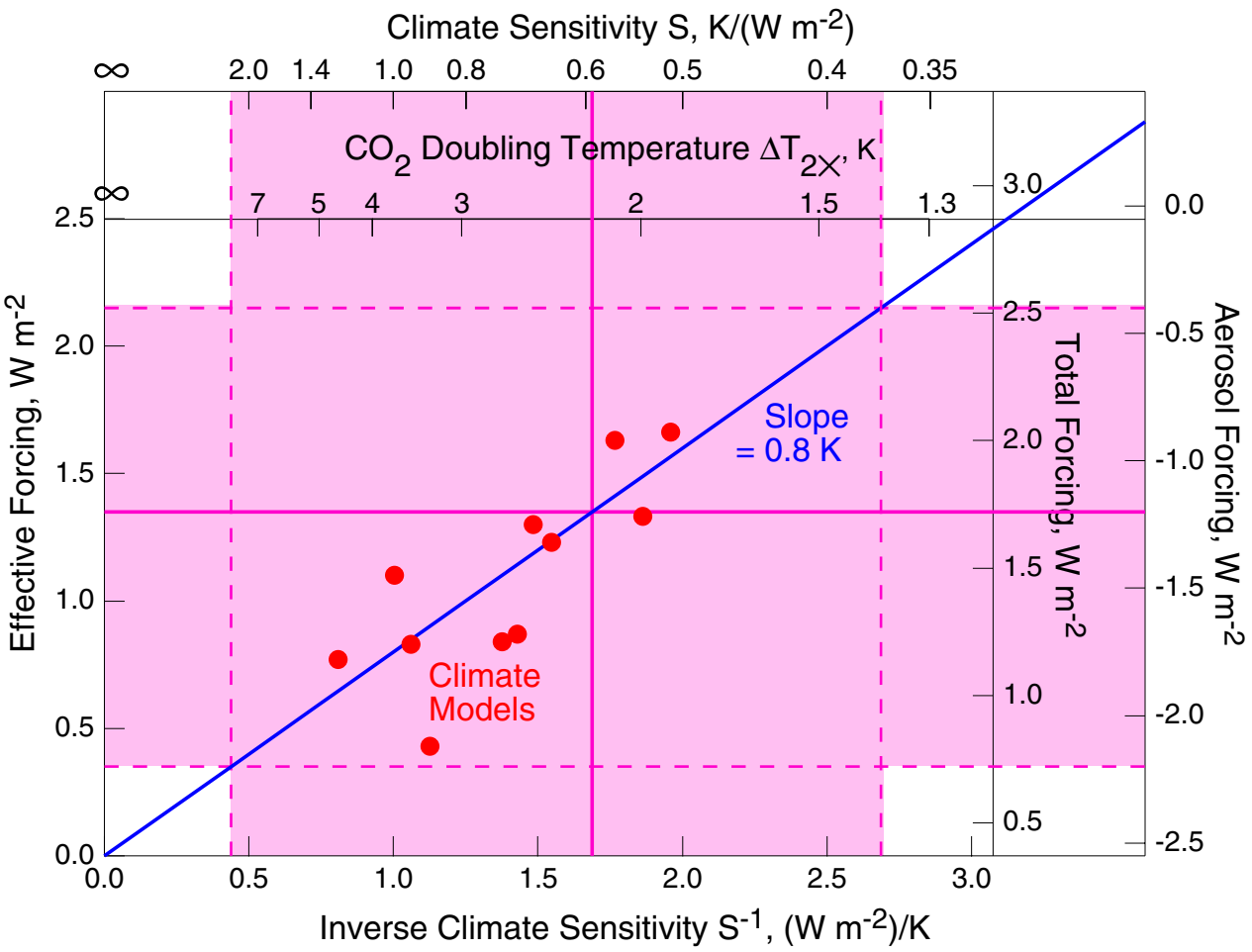
CLIMATE MODEL DETERMINATION OF CLIMATE SENSITIVITY

Effect of uncertainty in forcing

$$F_{\text{eff}} = F - H$$

$$\Delta T = SF_{\text{eff}}$$

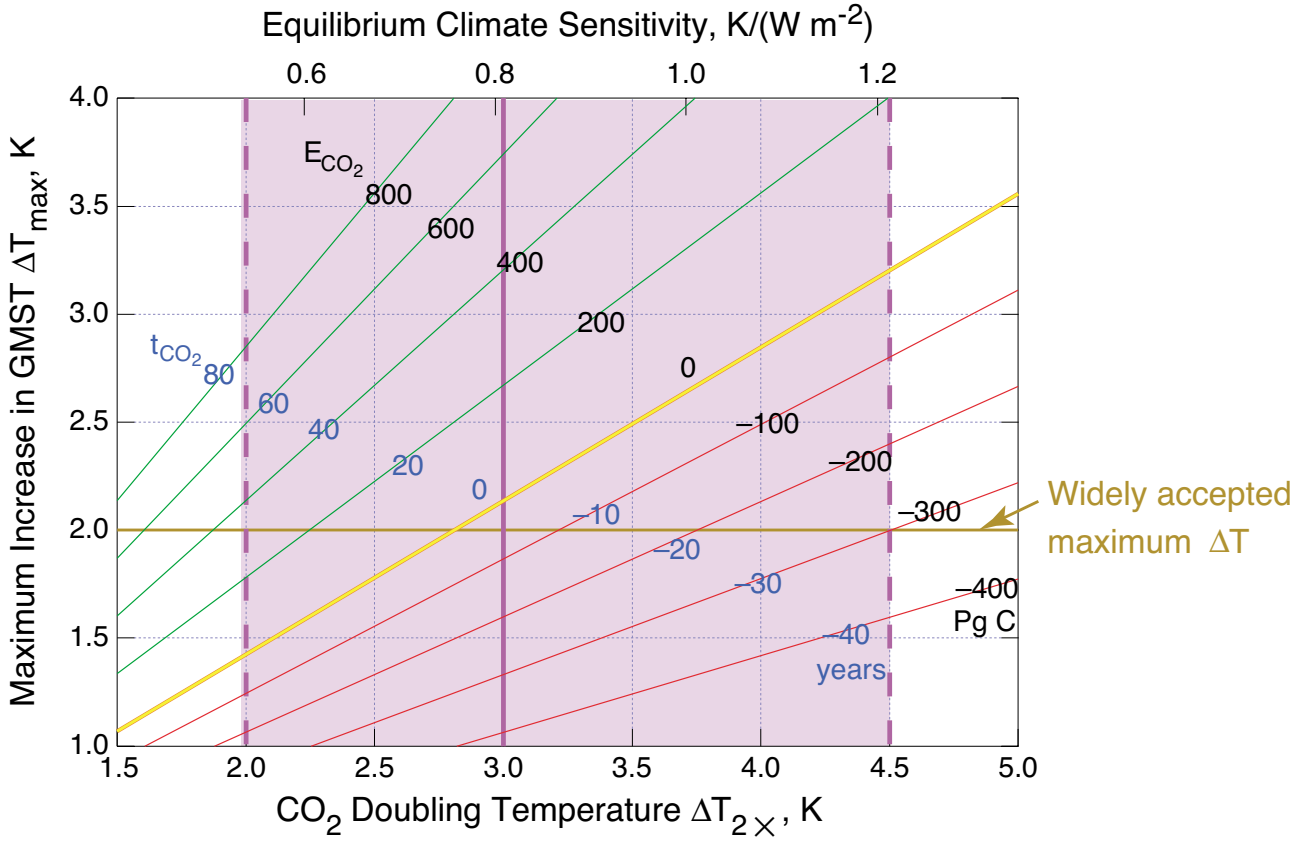
$$F_{\text{eff}} = \Delta T S^{-1}$$



Uncertainty in aerosol forcing allows climate models with widely differing sensitivities to reproduce temperature increase over industrial period.

ALLOWABLE FUTURE CO_2 EMISSIONS

Dependence on climate sensitivity and acceptable increase in temperature relative to preindustrial



For $\Delta T_{max} = 2$ K . . .

If sensitivity $\Delta T_{2\times}$ is 3 K, ***no more emissions***.

If sensitivity $\Delta T_{2\times}$ is 2 K, ~ ***30 more years of emissions at present rate***.

If sensitivity $\Delta T_{2\times}$ is 4.5 K, ***threshold is exceeded by ~30 years***.

THE PATH FORWARD

Determine aerosol forcing with high accuracy.

Multiple approaches are required:

Laboratory studies of aerosol processes.

Field measurements of aerosol processes and properties: emissions, new particle formation, evolution, size distributed composition, optical properties, CCN properties, removal processes . . .

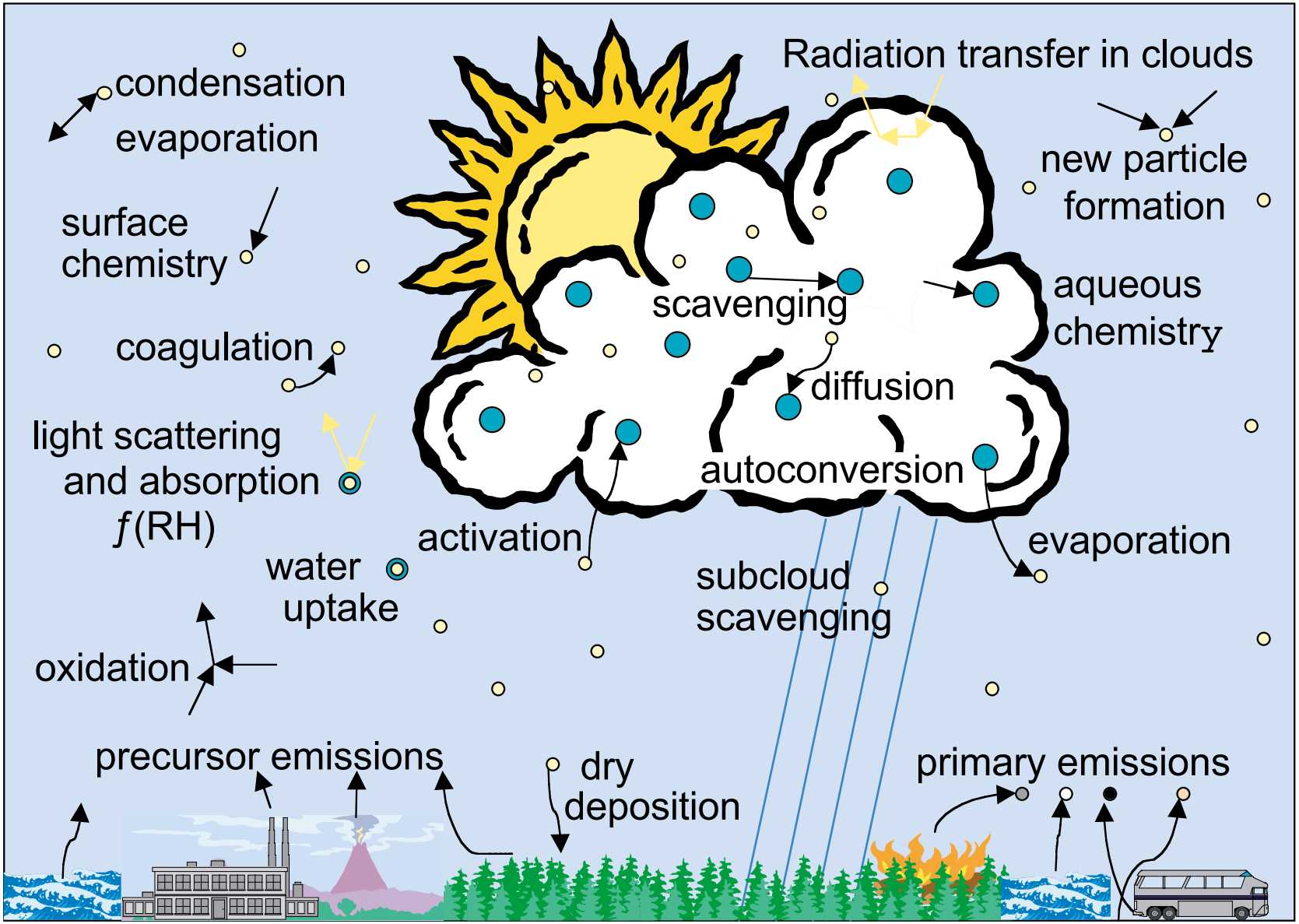
Represent aerosol processes in ***chemical transport models***.

Evaluate models by ***comparison with observations***.

Satellite measurements for spatial coverage.

Calculate forcings in ***chemical transport models and GCMs***.

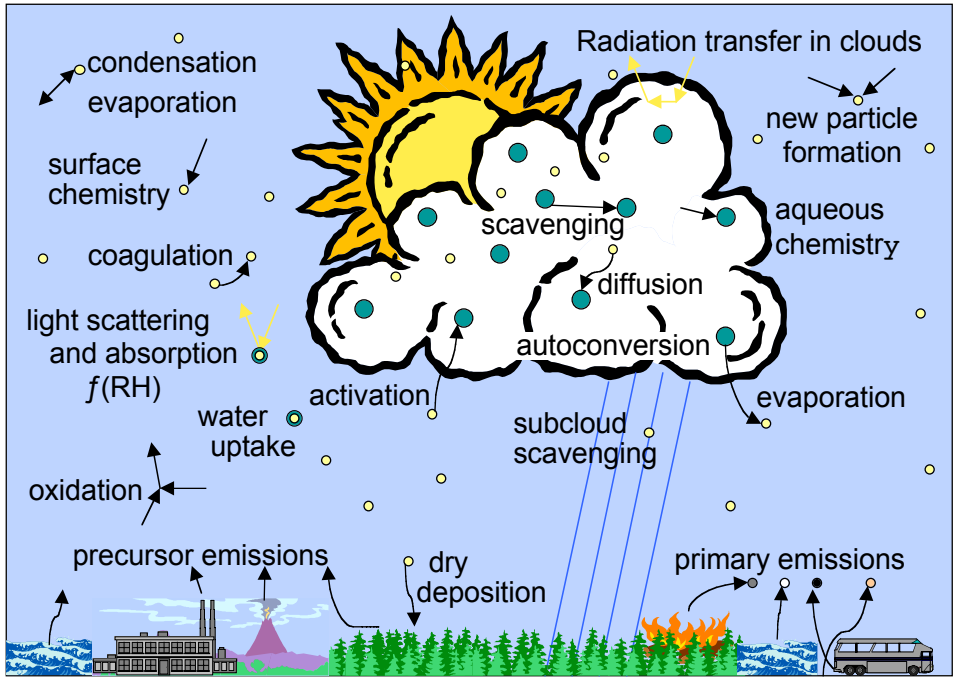
AEROSOL PROCESSES THAT MUST BE UNDERSTOOD AND REPRESENTED IN MODELS

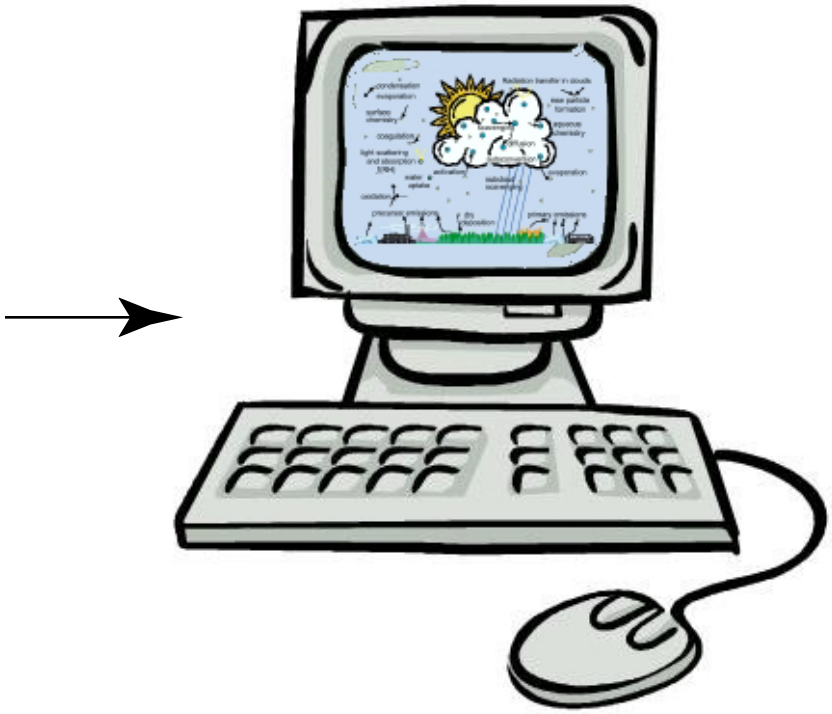


Modified from Ghan and Schwartz, Bull. Amer. Meterol. Soc., 2007

APPROACH TO DETERMINE AEROSOL FORCING

Numerical simulation of physical processes



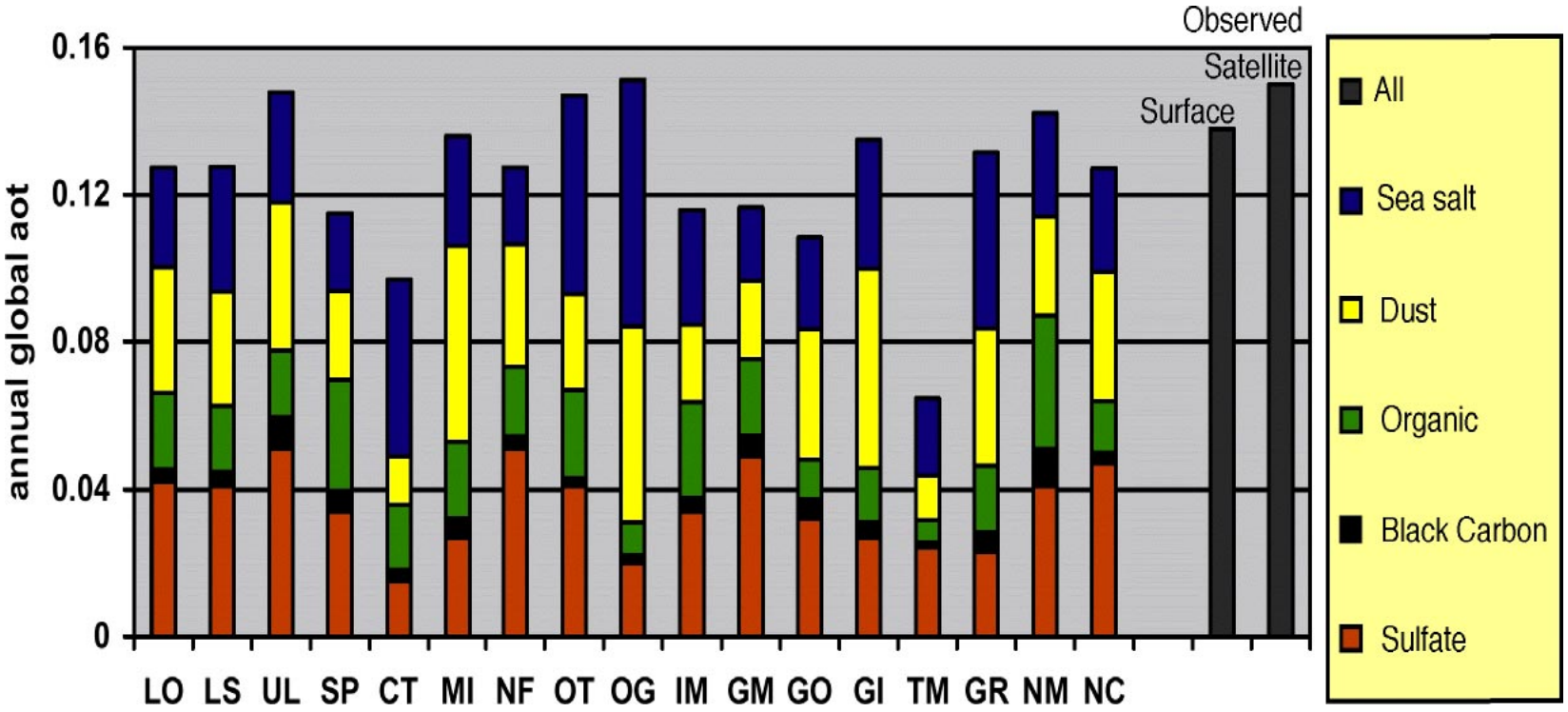


Isomorphism of processes to computer code

Modeling aerosol processes requires understanding these processes, developing and testing their numerical representations, and incorporating these representations in global scale models.

AEROSOL OPTICAL DEPTH IN 17 MODELS (AEROCOM)

Comparison also with surface and satellite observations



Kinne et al., ACP, 2006

Surface measurements: AERONET network.

Satellite measurements: composite from multiple instruments/platforms.

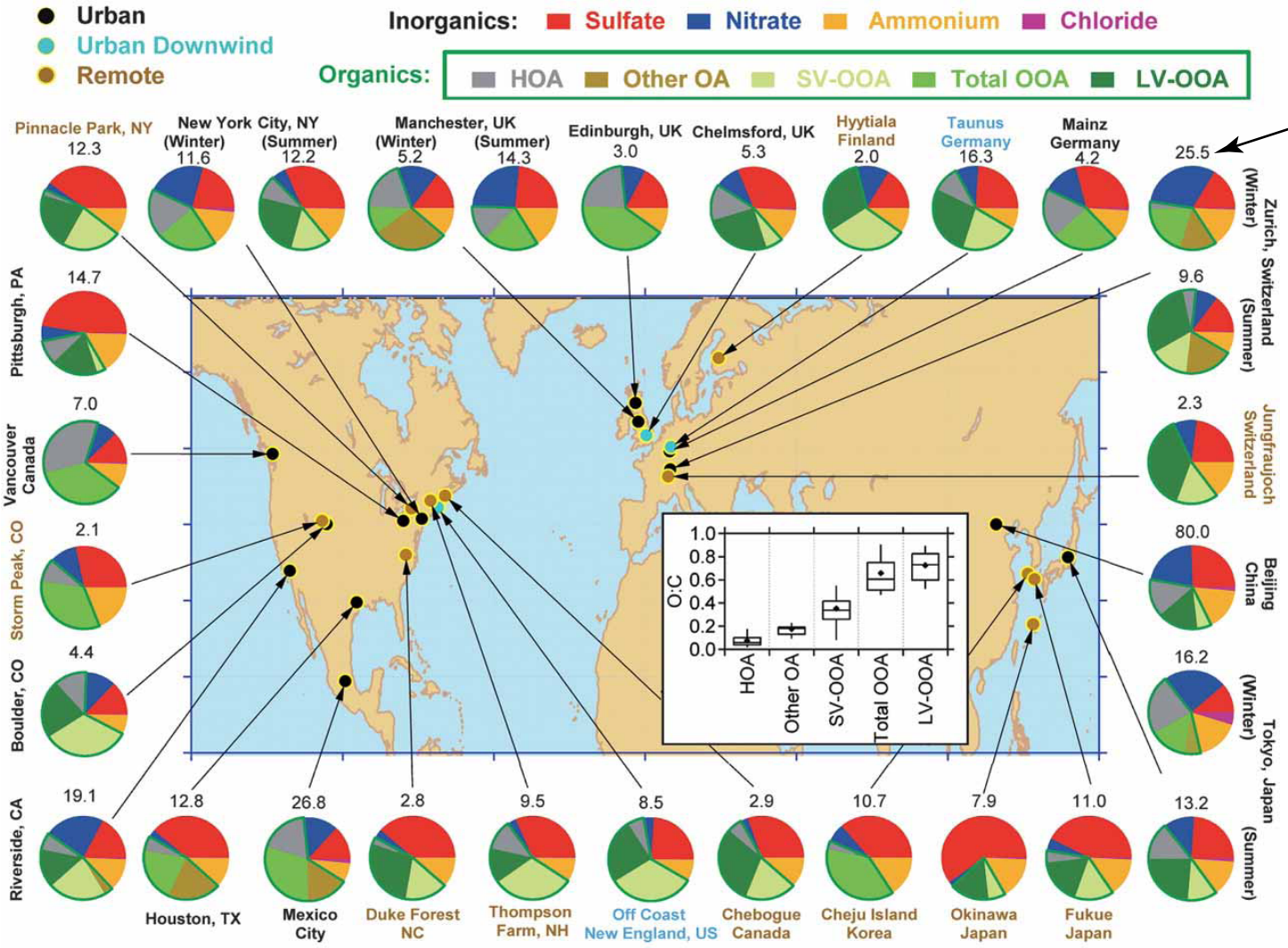
Are the models getting the "right" answer for the wrong reason?

Are the models getting the "right" answer because the answer is known?

Are the satellites getting the "right" answer because the answer is known?

ORGANIC CONTRIBUTIONS TO TROPOSPHERIC AEROSOL

Mass-spec determination of primary vs secondary organics

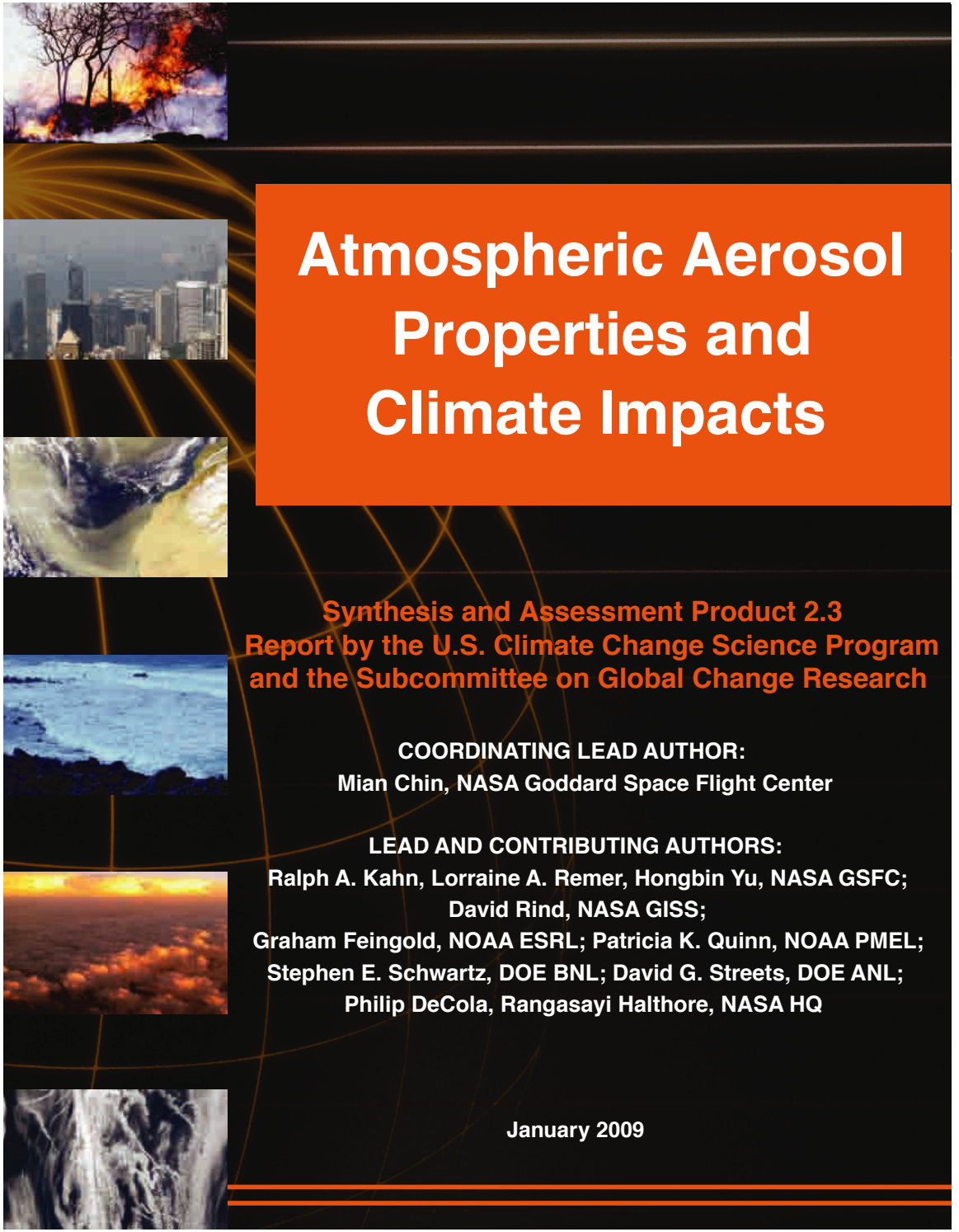


Evolution of Organic Aerosols in the Atmosphere
J. L. Jimenez, *et al. Science* **326**, 1525 (2009)

New analytical techniques permit identification of formation mechanisms.

Recent review of aerosol influences on climate

www.climatescience.gov/Library/sap/sap2-3



IMPORTANCE OF KNOWLEDGE OF CLIMATE TO INFORMED DECISION MAKING

- The lifetime of incremental atmospheric CO_2 is about 100 years.
- The expected life of a new coal-fired power plant is 50 to 75 years.

Actions taken today will have long-lasting effects.

Early knowledge of climate sensitivity can result in huge averted costs.